ThermoMap – An Open Source Web Mapping Solution for Visualising Very Shallow Geothermal Energy Potentials

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Abstract. ThermoMap is an EC co-funded project (FP7-ICT Policy Support Programme) and focuses on mapping of very shallow geothermal energy potentials (‘vSGP’) in Europe.

Existing soil, climate, topographic and hydrological data on small (European Outline Map) and local scale (test areas) have been derived, harmonised and analysed in order to estimate the geothermal potential up to a maximum depth of ten metres below surface. 14 detailed test areas of the nine ThermoMap partners from Austria, Belgium, France, Germany, Greece, Hungary, Iceland, Romania and United Kingdom have been defined and investigated in detail.

The visualisation of results is facilitated by an Open-Source WebGIS with its interface, the ThermoMap MapViewer, which is intended for end users, planners, engineers, politicians and scientists, to give them an overview and detailed information about the local geothermal conditions of single properties or entire administrative units.

The MapViewer is tailored to the project requirements and concentrates on bringing together the distributed data sources and getting meaningful compiled information of a specified location. For this a special query tool was developed (‘vSGP Infobox’), that can also be printed as a Local Information Sheet enriched with map details and diagrams (‘Report’). Additionally a calculation tool is incorporated in the system, in order to

calculate individual results with external data from investigations ('vSGP Calculator') and to improve the result quality.

Keywords: very shallow geothermal potential, renewable energy resource, heat conductivity, Open-Source WebGIS, Web Mapping, OGC, Web Map Service, OpenLayers

1. Introduction

Due to climate change and new political developments to use more renewable energy forms (turning away from nuclear, coal and other non-renewable resources), alternative energy sources are needed. Therefore, the geothermal energy sector can become one of the important energy resources in the future.

Geothermal energy (heat) is CO_2-neutral, quasi-inexhaustible and available decentrally at any time and almost everywhere. The exploitation of deep geothermal resources for producing electricity is not only an important component for creating innovative and renewable energy systems, but the use of shallow (focus: up to 400 metres depth) and even very shallow (focus: up to 10 metres depth) geothermal potentials is also significant, e.g. for sustainable heating and cooling of residential and industrial buildings, etc. The very shallow geothermal energy within the first ten metres below the Earth's surface is predominantly influenced by solar energy input rather than by the core of the Earth. Furthermore, in Europe the installation and operation of very shallow heat collector systems is not as restricted by national and regional legislation as for deeper systems. Compared with the well-researched and already implemented solar, wind and hydropower domains, less research has been done in the analysis of very shallow geothermal energy potentials at the European level.

Potential analysis for decision support in regional and landscape planning are not new, but its derivation and spatial visualisation for the first ten metres are so far done little. In addition to the introduction of the derivation concept of the very shallow geothermal potential, which is expressed by the parameters of thermal heat conductivity and volumetric heat capacity, the focus of the article is on the WebGIS based visualisation of the results.

2. Methodology

2.1. European Outline Map and Test Areas

The ThermoMap project (http://www.thermomap-project.eu/) is divided into two parts. The European Outline Map ('EOM') at a scale of 1 : 250,000 aims to give an overview of the shallowest zone's geothermal conditions in terms of thermal heat conductivity for the whole of Europe. It is based mainly on the European Soil Database ESDB v2.0. (Panagos et al. 2012)

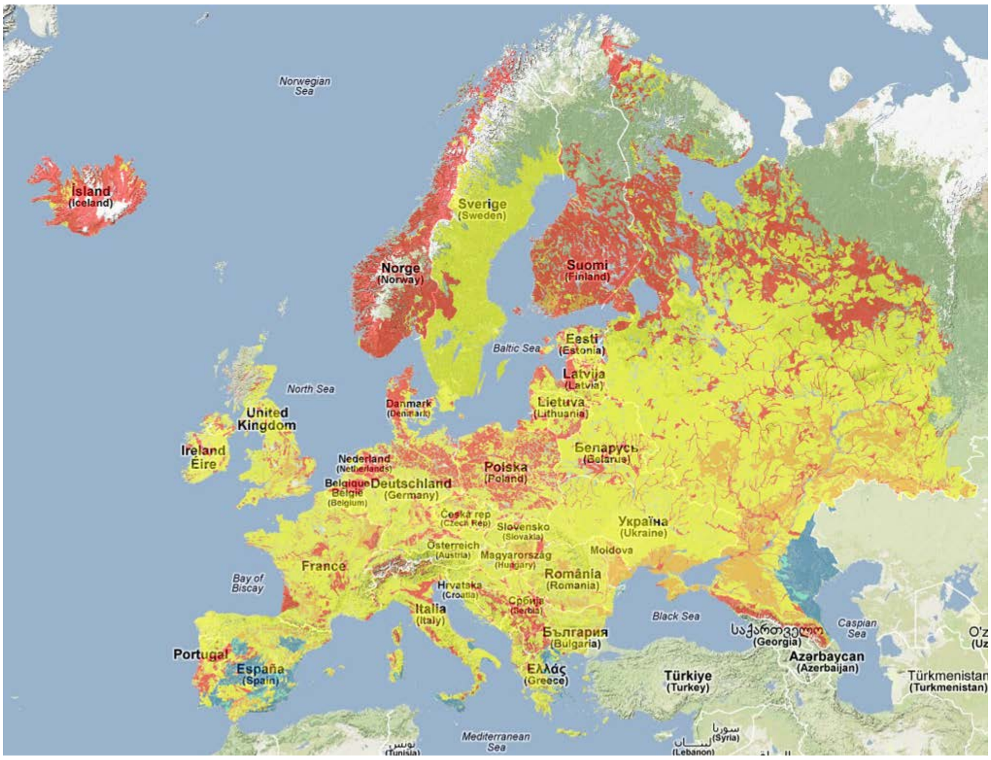


Figure 1. European Outline Map

Whilst, 14 test areas at differing scales (1 : 5,000 to 1 : 40,000) have been investigated to illustrate the very shallow geothermal energy potential (vSGP) in detail. Within these test sites, the depth range covered is up to 10 metres, provided that it consists of soil and soft rock zone since drilling into hard rock is not considered as expedient with regard to technical and economic aspects. Furthermore, the complete depth range is divided into three layers (0-3 metres, 3-6 metres and 6-10 metres) based on the different types of very shallow heat collector system technologies available.

2.2. Database, data preparation and processing (Test Areas)

Database

The parameters used to derive the energy potential are as follows climatological (mean annual temperature, annual precipitation), pedological (soil type, grain size distribution in the three depth levels, thickness of the softrock zone and bulk density), hydrological (depth of groundwater table), geological, topographic (terrain slope) and administrative (e.g. usage limitations in conservation areas) spatial data sets.

Data preparation

A uniform classification of the grain size distribution was the key part of the transnational harmonisation of the partner country data bases. National systems were transferred to the USDA soil texture triangle (United States Department for Agriculture) (Berry et al. 2007).

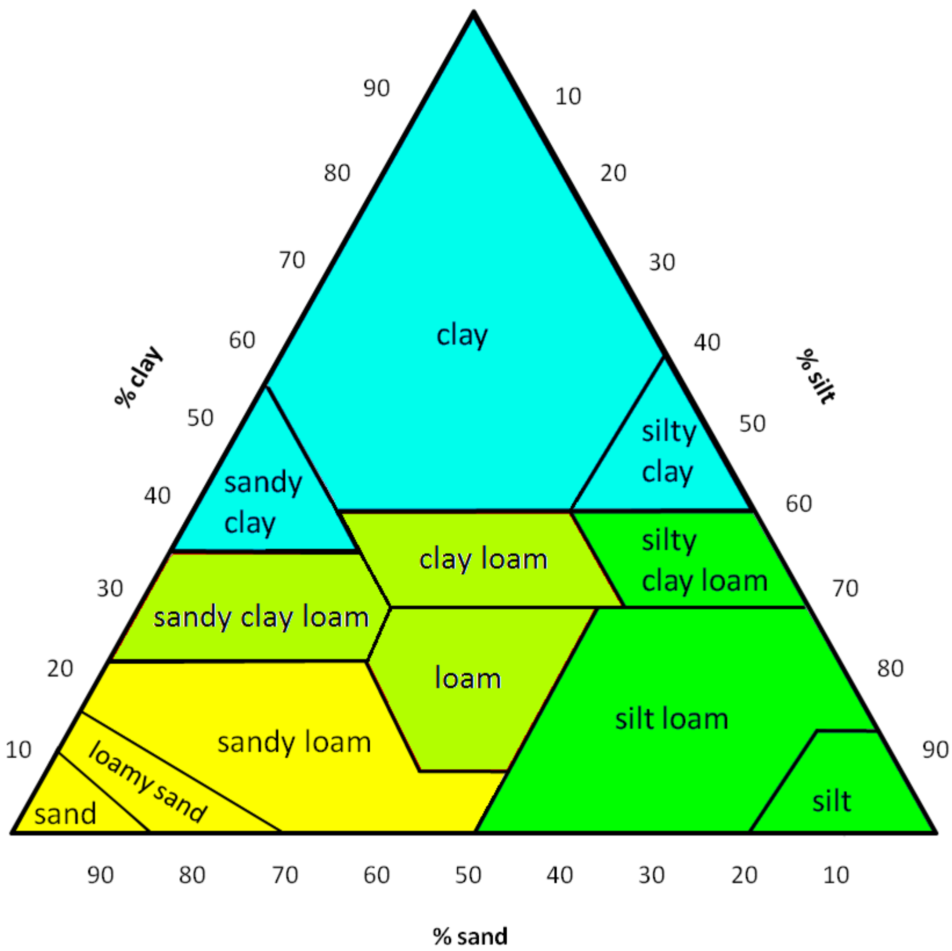


Figure 2. USDA soil texture triangle

In the case of absent data, information had to be estimated or generated by interpolations using measured point data. This concerns e.g. the thickness of the soft rock zone and soil properties in deeper layers below three metres. The average depth of the groundwater table had to be obtained in some cases by pedotransfer functions. In case of inconsistent or inaccurate data, the corresponding areas were removed from the estimation.

To ensure consistent processing of the analysis at test area level, the consortium consolidated data formats and processing steps. These agreements allow a harmonised and cross-nationally comparable representation of the potential maps.

Data processing and analysis

In consultation with industry representatives (e.g. Rehau) and scientists of the ThermoMap consortium the concept of Dehner et al. (2009) and the modelling approach after Kersten (1949) and Dehner (2007) have been selected to calculate the very shallow geothermal potential.

Each USDA soil texture class has specific values for air capacity, field capacity, dead water content and thus the maximum pore volume. With increasing depth also increases the bulk density, which was used as average fixed value for the calculation. For each depth level and soil texture class precalculated values of heat conductivity were compiled in a table, which had been calculated using the Kersten formulas. These are to be assigned to the individual potential areas by the project partners depending on the saturation conditions (groundwater influence) and humidity index. (calculated according to Schreiber 1973) The heat capacity, however, is calculated by each partner itself with the Dehner formulas using specific values for field capacity, dead water content, maximum pore volume, then humidity index, saturation, bulk density and annual mean temperature.

Areas with insufficient data, as well as areas in which no usage is possible (no existing soft rock or less than 3 metres thickness, water bodies) are excluded from the analysis. Usage limitations (protection zones, unsuitable soils types and steep terrain) are taken into account, however, visualised with a special hatching.

The results as well as all background data are integrated in the spatial database of the MapViewer.

2.3. WebGIS – System and Technology

System components

The WebGIS system consists of three components: client (= Web browser), a central web server with the European data and the client application (= online accessible WebGIS interface) and the partner servers with the test area data. The data is collected from distributed data sources (the partner servers), visualised and queried in a comprehensible way.

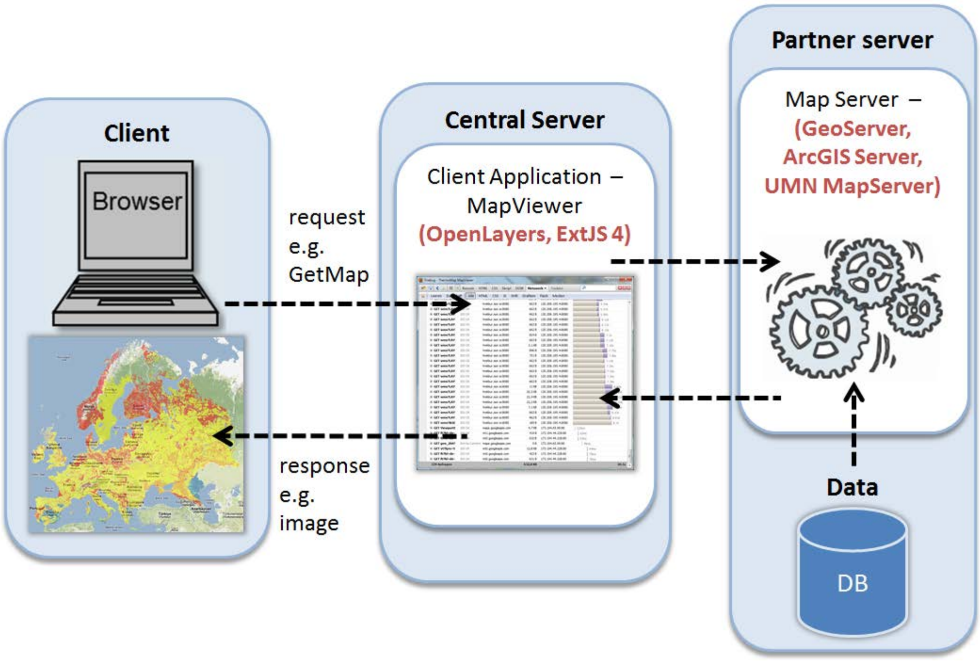


Figure 3. WebGIS system components

Distributed data

The distributed data storage is the most important principle in the project context. The data of the 14 test areas are spread across nine partner servers. In the WebGIS, no spatial analyses are performed since the partners process the data in their local GIS environment. It remains on the partner servers, from where it is published as WMS layers. The technologies used from the partners for the publication of WMS layers are different, including ESRI ‘ArcGIS Server’ and open-source ‘GeoServer’ with underlying PostGIS database, but the data structure and compliancy to Open Geospatial Consortium (OGC) standards to retrieve the required information are predetermined. The WMS layers of the Hungarian test areas e.g. are published using the proprietary map server of ESRI ‘ArcGIS Server’. The interoperabilty between open-source and proprietary technologies, however, is not the best and entailed some necessary adaptations.

Issues caused by using different map server technologies

The available map server software and the existing knowledge about it on the partner side are the reasons why different technologies are used which

caused some additional adaptations on both sides, the partners' and the client application side.

First, the default map projection EPSG:900913 of the Google base maps (Spherical Web Mercator) has been transformed to the EPSG:3857 projection that is basically the same with identical coordinates, but supported by 'ArcGIS Server', too.

Then, to avoid setting problems of 'ArcGIS Server' with the maximum width of single untiled map images, this was solved by using tiled map images which the MapViewer is assembling while loading the images.

The main challenge was the right format of the GetFeatureInfo response which retrieves feature information for a clicked map location. WMS layers provided by 'ArcGIS Server' don't support by default the GML format that is preferred by the open-source software, ready to use and returns single features with geometries and attributes.

There is another standard format 'text/html' that should be supported by default from all map servers, that returns tables (written in HTML) which can be displayed as they are, but this format is rather inflexible in order to get the single attribute names and associated attribute values from the HTML response as it is needed for the project specific output, the vSGP Infobox and the Report tool. Since three project partners are using 'ArcGIS Server' for providing WMS layers, with much time and effort the programming code has been changed. From the HTML-table the single headers and rows are read and combined to the desired feature attributes.

Providing OGC standard compliant WMS layers with the proprietary 'ArcGIS Server' brought up some challenges on the partner side, too. ESRI strongly urged users of ArcGIS Server software to use a „developed-for-publication-purposes" format named MSD for the creation of map services. Although this format provides a slightly better performance in speed, in terms of providing OGC compliant WMS services it causes some trouble. Basically it returns a distorted image for the GetLegendGraphic request, which causes the ThemoMap MapViewer's layers' legend to show graphically objectionable result. The ultimate solution for this problem was to revert for the MXD-based map service along with reconfiguration of the legends of each layer.

The user isn't aware necessarily of all performed adaptations on server and client side and of getting data from different servers provided by different technologies since the MapViewer presents the collected information in a homogeneous way.

Open-Source Technology

The WebGIS interface was developed using the open-source frameworks OpenLayers and ExtJS 4 (Morper-Busch 2012). Both are JavaScript application programming interfaces which make it possible to combine interactive maps with a complex user interface. OpenLayers' functionality is enhanced with GUI components of ExtJS 4, which are required for a demanding layout of map windows, toolbars, map layer trees and legend windows by which the user can interact with the application. The pure client-side JavaScript application is therefore independent of any server technology.

WMS requests from the client, via the client application, are sent to the partner servers, which then return the desired responses to the client. Request and response formats are standardised by the OGC. The used WMS requests are *GetCapabilities*, *GetMap* for georeferenced map images, *GetLegendGraphic* for legend symbols and *GetFeatureInfo* for attribute values of map layers of a specified map pixel.

2.4. WebGIS Interface (MapViewer)

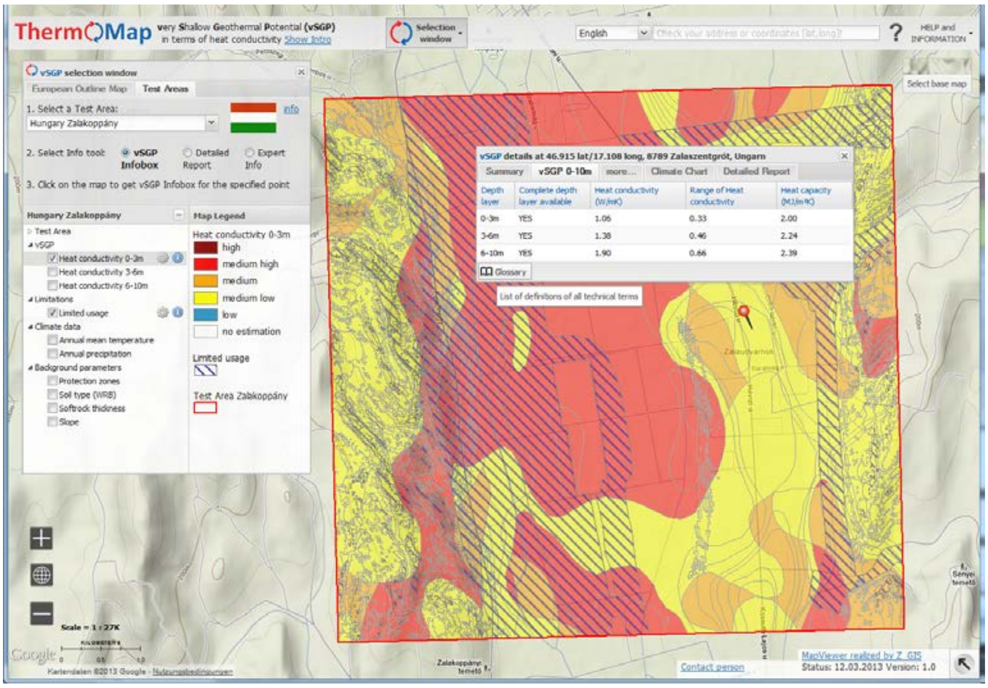


Figure 4. ThermoMap MapViewer showing one of the Hungarian test areas, the vSGP Infobox displays compiled values for a specified map location.

Target groups

The ThermoMap MapViewer (http://thermomap.edu-zgis.net/) is intended for use by the public, for planners and engineers, public bodies, and scientists, in order to provide an overview or, in the case of different test sites across Europe, more detailed information and usable data about the geothermal conditions. Private users may check the potential of their residential district; community planning and administration authorities may test the geothermal potential of their entire administrative unit. To avoid confusion for non-experts the MapViewer is graduated in different information levels.

Web mapping usability

The ThermoMap MapViewer follows the map viewer principles that are developed in cooperation of Z_GIS (University of Salzburg) with RSA (Research Studios Austria) iSpace Salzburg in order to communicate spatial content and results of projects with the focus on open-source technology and considering the results of the usability research. (Mittlböck et al. 2012). The guidance of the user to the main contents of the project is particularly important for the acceptance of an application. For this precise instructions were designed to explain the step-by-step workflow. ("1. Select test area", "2. Select info tool", "3. Click on the map"). The aim is the intuitive understanding of the intended application; the required actions are reduced to a minimum. In any case the user should not be deflected of the essence through to extensive toolbars.

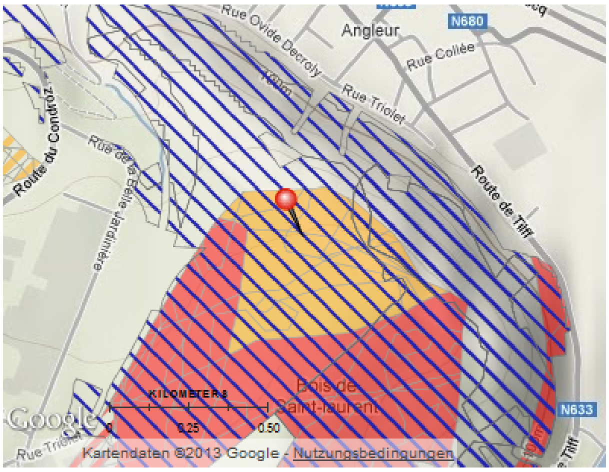
vSGP Infobox and Report

With a special query tool (‘vSGP Infobox‘), using the GetFeatureInfo response, a clear compilation of all necessary background parameters and results is shown for a selected map location, which can also be displayed in a report as a printable Location Information Sheet (‘Report’) which contains up to five pages, enriched with map details and schematic diagrams.

EU project ThermoMap - Belgian Test Area: City of Liège
Location Information Sheet for the very Shallow Geothermal Potential from 15/03/2013

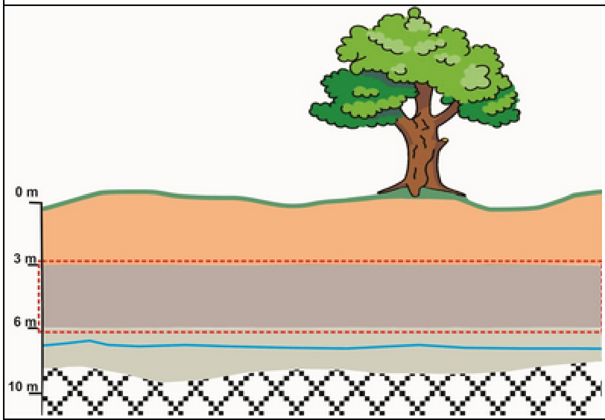
Address and location:
4031, Belgien
50.6077° latitude and 5.5976° longitude

ThermoMap



Map legend 3 – 6m:
Heat conductivity
- high
- high (partial)
- medium high
- medium high (partial)
- medium
- medium (partial)
- medium low
- medium low (partial)
- low
- low (partial)
- no estimation

Limited usage



Schematic diagram 3 – 6m:

Depth layer 3 – 6m

Estimated groundwater table

Hard rock

Geothermal situation 3 – 6m

The thermal heat conductivity of the soil matrix is defined essentially by its texture, water content and bulk density. At the chosen site at 3 – 6m depth the ***grain size*** according to the USDA classification is determined as ***loam***. The classification precision is ***Level 1***. The ***heat conductivity*** under unsaturated conditions can range from ***0.90 W/mK*** to ***1.26 W/mK***. For the prevailing ***humid/ unsaturated conditions*** it is estimated as ***1.26 W/mK***. These parameters were calculated according to the KERSTEN (1949) formulas. The ***heat capacity*** of ***2.02 MJ/m³K*** is calculated according to formulas after DEHNER (2007). For the calculations a predefined value had to be assumed for the ***bulk density***. Within this depth layer the applied value is ***1.5 g/cm³***.
In summary, it can be stated on the basis of the presented geoscientific parameters that the chosen location shows a *medium conductivity* with ***possible limitations*** for the utilisation of the very Shallow Geothermal Potential (vSGP) in terms of heat conductivity: There is occurence of *protection zone*.
For full system design please contact a shallow geothermal consultant.

Figure 5. The fourth page of a report for a Belgian map location

Enhanced usability

Some extensions that were not planned in the beginning are mainly owed to the need of user understanding of the background, data sources, processing, results and intended purpose of the project. These enhancements also emerged in the course of user and promotional seminars (held within the partner countries since November 2012) and the outcomes of the MapViewer usability questionnaire (available from December 2012 to February 2013) including translations to the project partner languages, help and information documents, a new Intro Window, layer information buttons for reading the layer specific metadata, and – very recently – the vSGP Calculator function for external data input.

2.5. vSGP Calculator

As the ThermoMap test areas are exemplary case studies, for the majority of locations the data output is only a first rough estimation of the very Shallow Geothermal Potential, since the European Outline Map is based only on available area-wide data of very generalised quality.

However, if detailed external data exists, for example from a local subsoil analysis or drilling hole descriptions, there is a possibility to improve the estimation results. The vSGP Calculator is intended to enhance existing data or generate new data.

The incorporated calculation function loads all available data from the European Outline Map for a specified map point to the calculator. The user can utilise the existing data or replace or amend it with own data. In general, the processing standards defined by the ThermoMap consortium are reproduced for a single map point calculating the vSGP with this tool. With the new calculated results an individual report as output can be printed.

Compared to the accuracy level of the European Outline Map, the calculator offers the possibility to reach at least the same or even a greater level of accuracy as in the Test Areas.

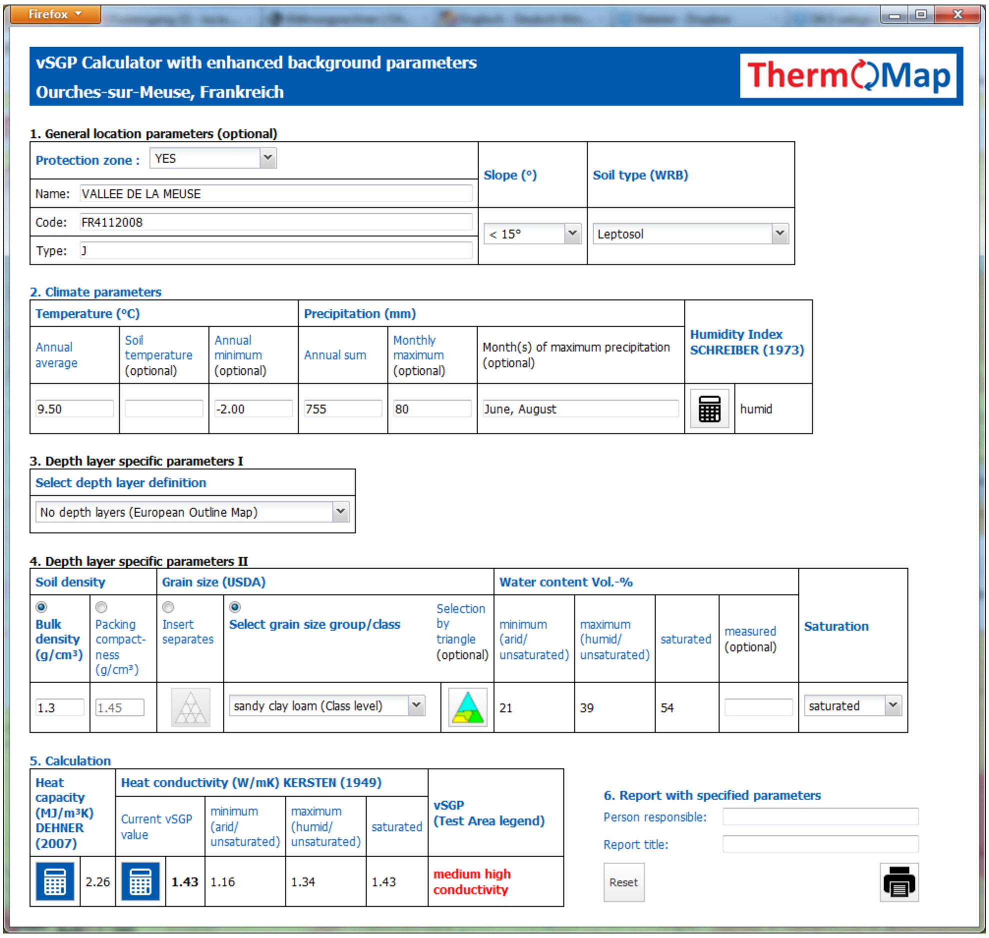


Figure 6. vSGP Calculator

3. Testing

In the testing phase of the project, the key objectives are to improve the user friendliness of the WebGIS visualisation system as well as to validate the estimation procedure by analysing soil and soft rock material from several test areas across Europe with regard to soil texture and thermal heat conductivity in order to optimise the developed system.

These measurements and the comparison of estimated with measured values will provide valuable data to the project consortium to validate the project results. First results at EOM and test area level show a good agreement between measured data, which have been interpolated to comparable mois-

ture content and bulk density values and the estimated soil texture and thermal heat conductivity values.

4. Conclusion and Outlook

In summary, it can be stated that the main objectives of the ThermoMap project have been achieved, in particular to develop a reliable and validated methodology of harmonising, standardising and calculating the necessary parameters for the estimation of very shallow geothermal energy potentials in Europe. Furthermore, a sophisticated WebGIS visualisation system has been developed which is accessible for all target groups. Planners and other stakeholders confirmed the benefit of the possibilities of both, the estimation procedure and the compiled information output system.

At the moment, the clear limiting factor for providing area-wide information in more detail is the poor data situation outside of the investigated case studies (Test Areas).

For single locations the specifically developed calculation tool (vSGP Calculator) is a good alternative to retrieve more detailed information, for whole regions potential maps can be generated by applying the developed rules of data harmonisation, standardisation, processing and analysis.

The transferability of the ThermoMap approach to other regions is given, however, the application of the research outcomes is beyond of the project's scope.

Nevertheless, it is planned to maintain the developed ThermoMap estimation tool for incorporating new or improved datasets and also keep the MapViewer and all related documents and information up to date. With regard to Europe's 2020 targets and the aimed turn away from fossil energy sources, this strategy can be regarded as a sustainable contribution to user needs concerning very shallow geothermal potentials as a regenerative energy resource in Europe.

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